COSMOS

COsmic-ray Soil Moisture Observing System

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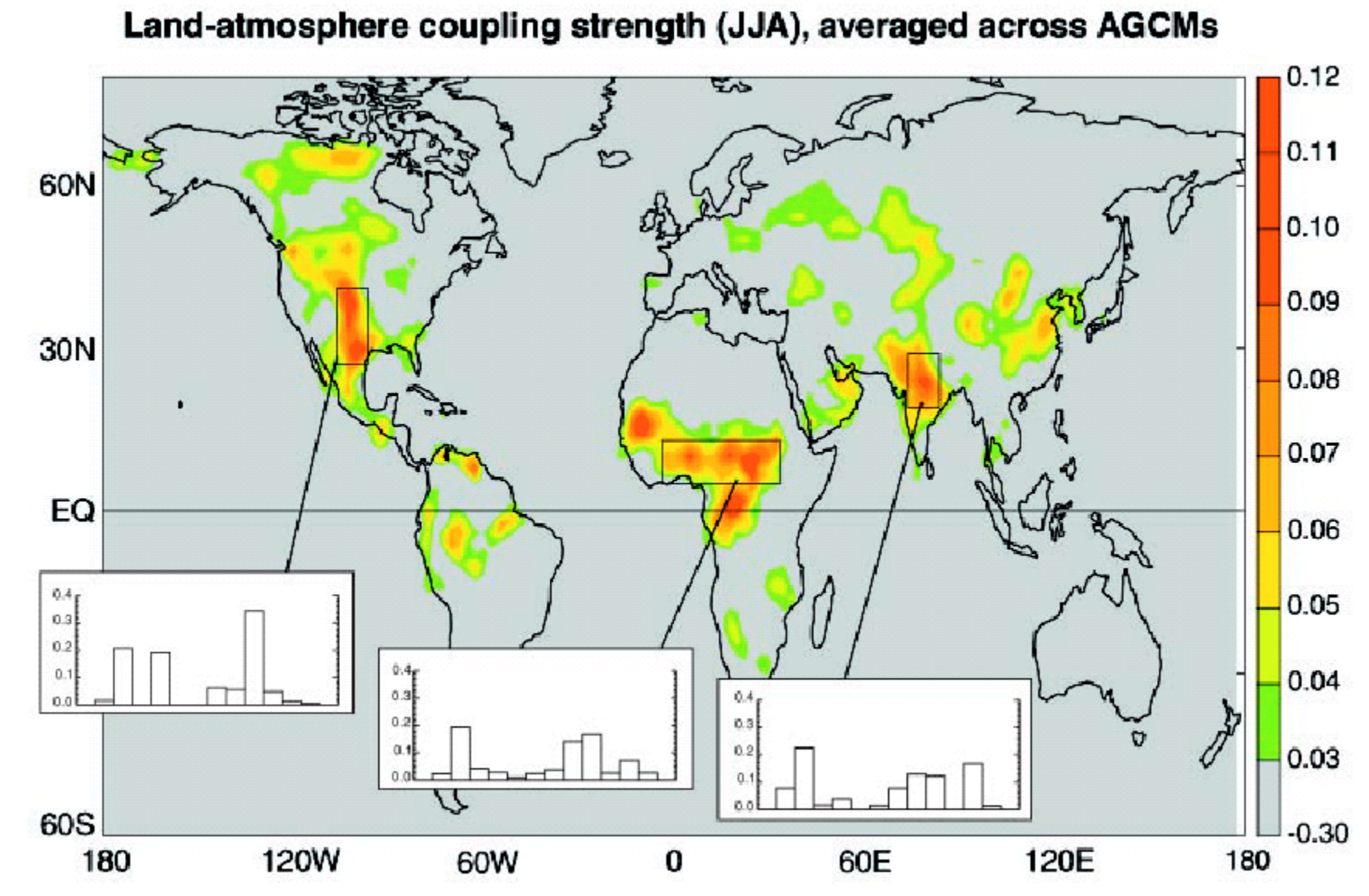
EMS Meeting, Amsterdam, 3 October 2008

The COSMOS

A network of cosmic-ray probes distributed throughout the contiguous USA

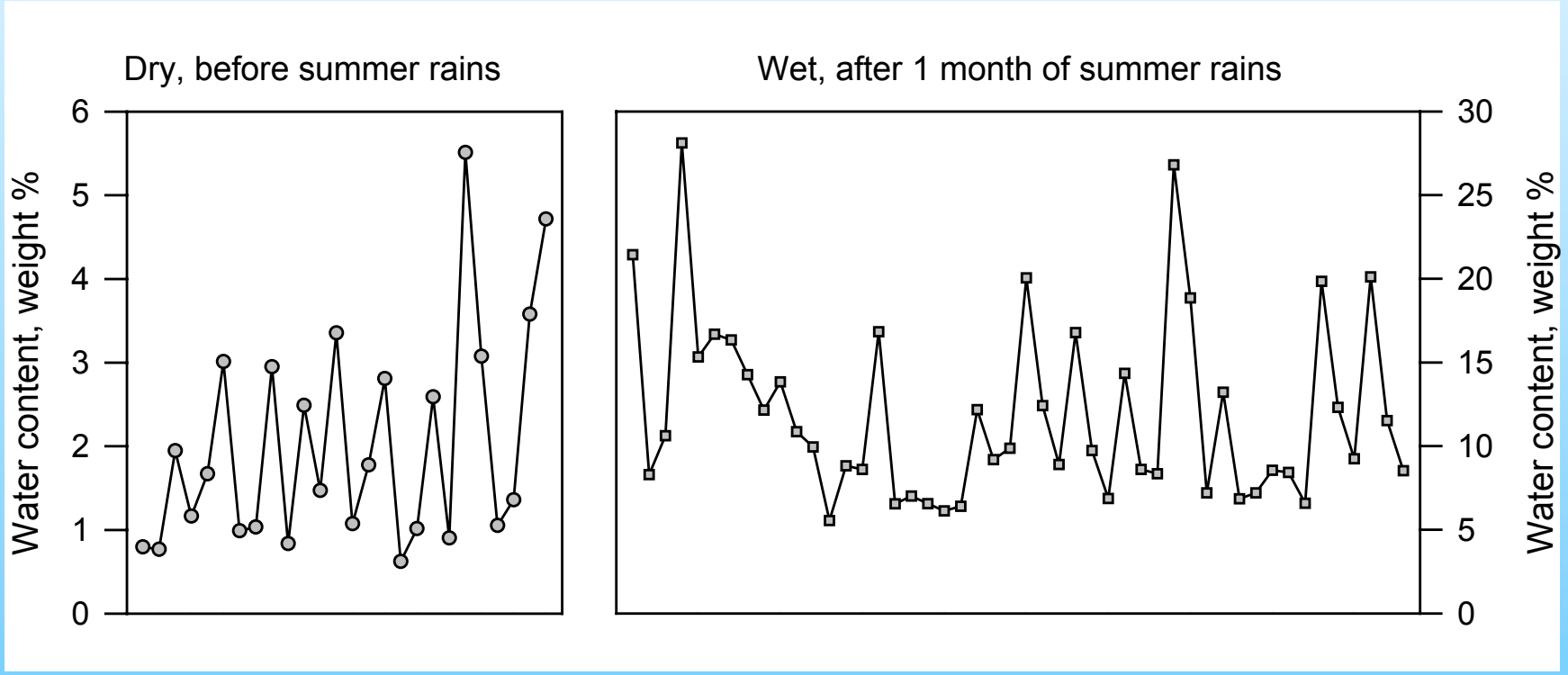
to provide soil moisture measurements at an intermediate spatial scale with arbitrary temporal resolution

Impact of soil moisture on precipitation

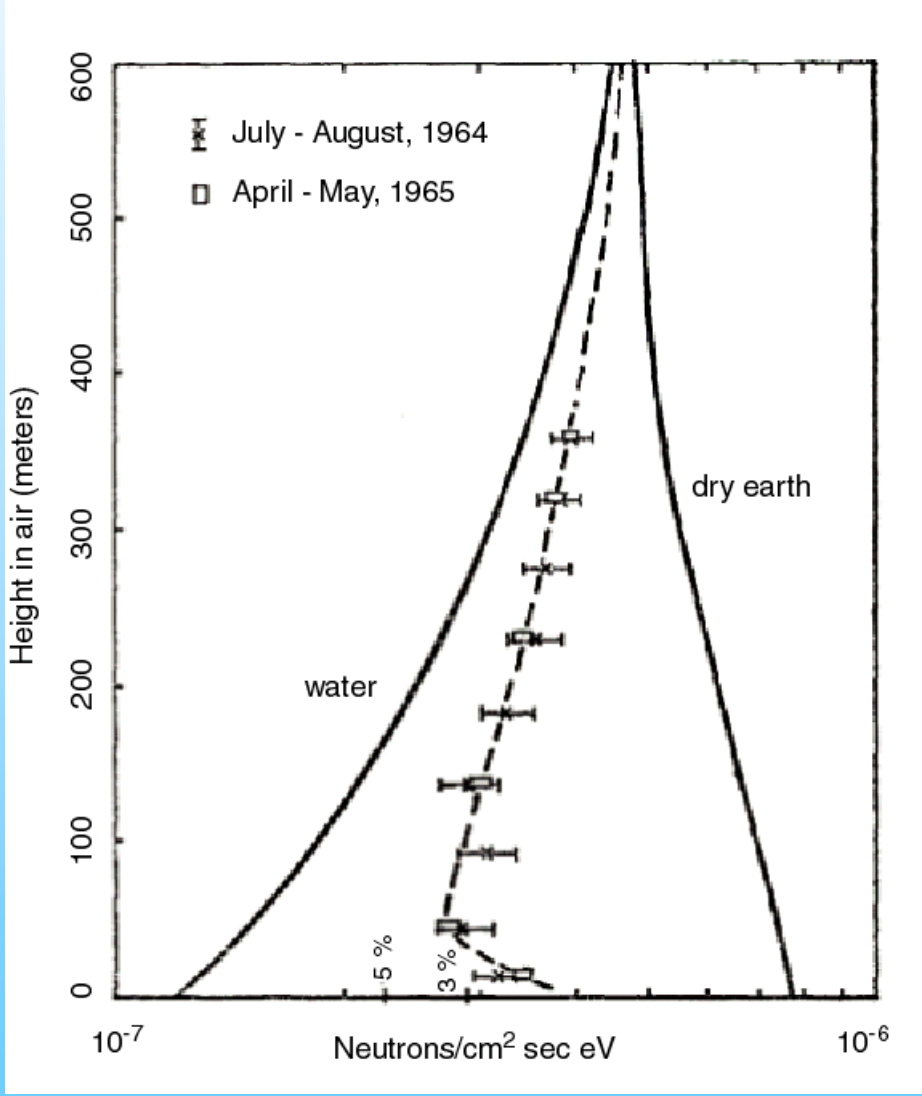


Spatial variations of soil moisture

(San Pedro River, AZ)

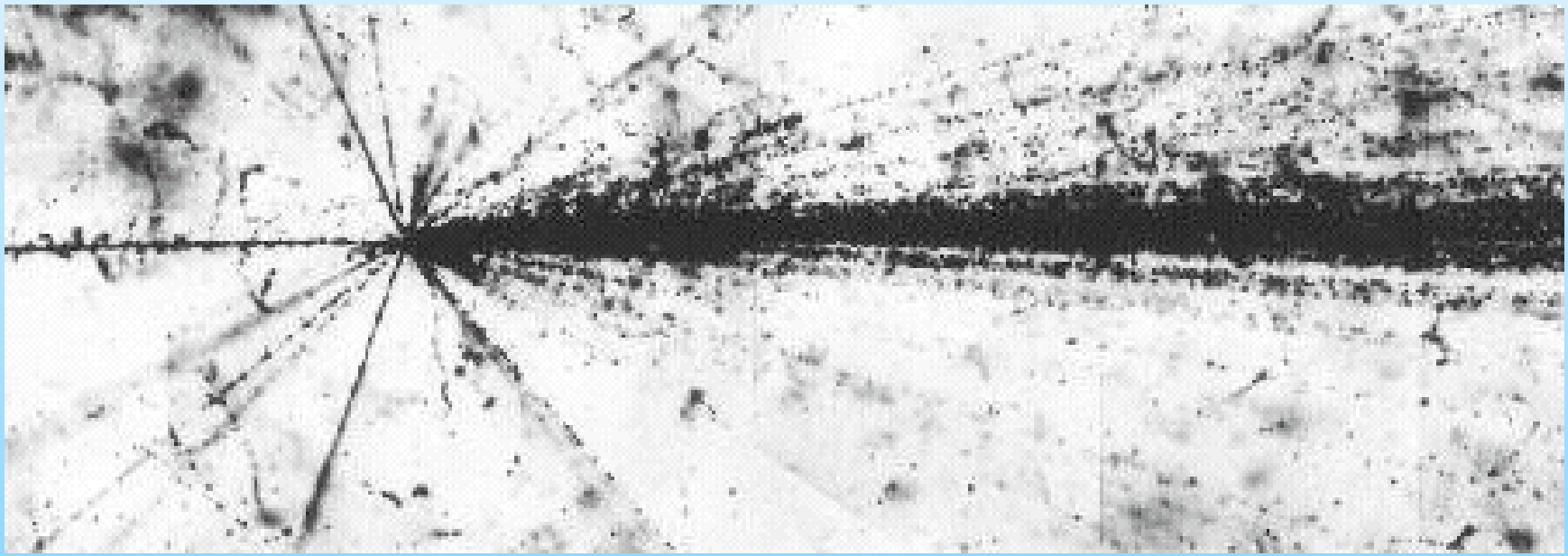


Cosmic-ray neutrons above the surface



Hendrick L.D. and R.D. Edge, 1966. Cosmic-ray neutrons near the Earth, Physical Review Series II, 145, 1023-1025.

Collision of cosmic-ray proton with atom



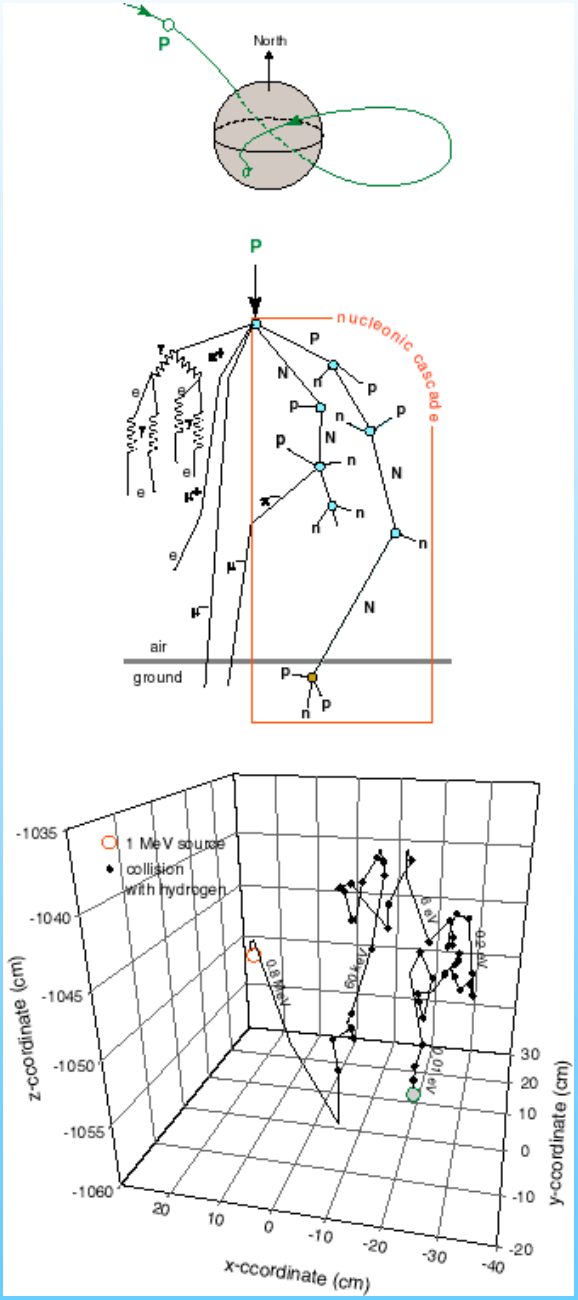
A collision between a high-energy cosmic ray particle and an atom in a photographic emulsion, as viewed through a microscope.

http://arc.iki.rssi.ru/mirrors/stern/Education/wcosray.html

Cosmic rays on Earth

- Primary - mostly protons and alphas
- Interact with magnetic field
  - intensity depends on geomagnetic latitude
- Interact with atmospheric nuclei
- Produce secondary particles - cascade
  - intensity depends on barometric pressure
- Produce fast neutrons
  - slowing down by elastic collisions
  - leads to thermalization
  - and then absorption

The last three processes depend on the chemical composition of the medium, in particular on its hydrogen content.



Space:

incoming high-energy cosmic-ray proton

Atmosphere:

generation of secondary cosmic rays

Ground:

slowing down thermalization and absorption

Moderating (slowing down) power

$$\phi\ (\mathrm{E}) = \frac{\mathrm{Q}}{\mathrm{E}\ \Sigma(N \cdot \sigma_{sc} \cdot \xi\ )}$$

ϕ (E) - flux of neutrons of energy E

Q - strength of source function

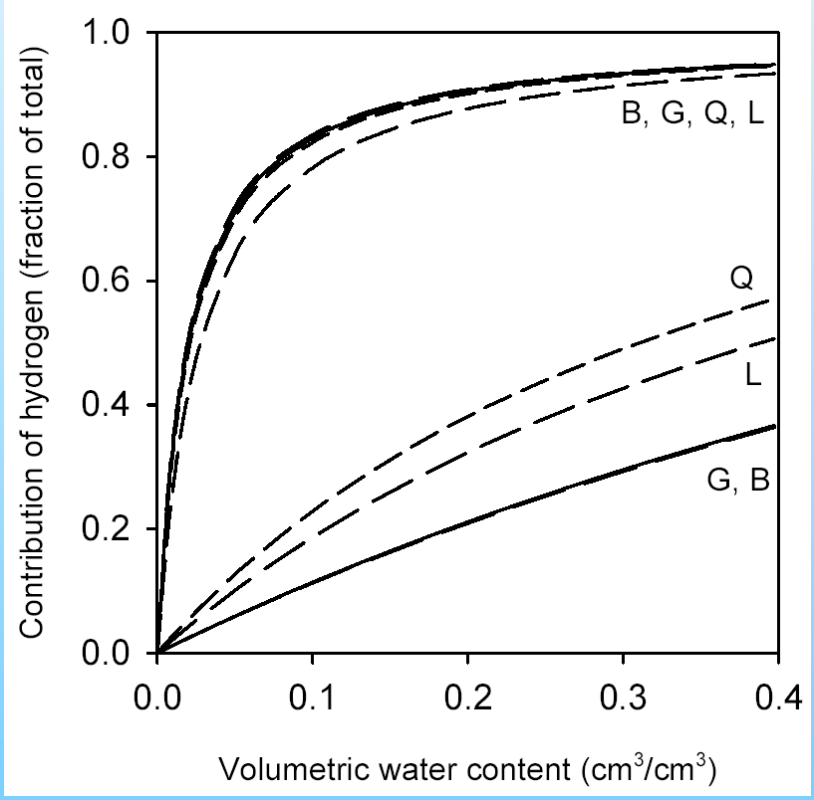
N - number of atoms of an element

σ_{sc} - scattering cross section for an element

ξ - log decrement of energy per collision

$\sigma_{sc} \cdot \xi$ - slowing down power for an element

$\Sigma(N \cdot \sigma_{sc} \cdot \xi)$ - slowing-down power of the medium



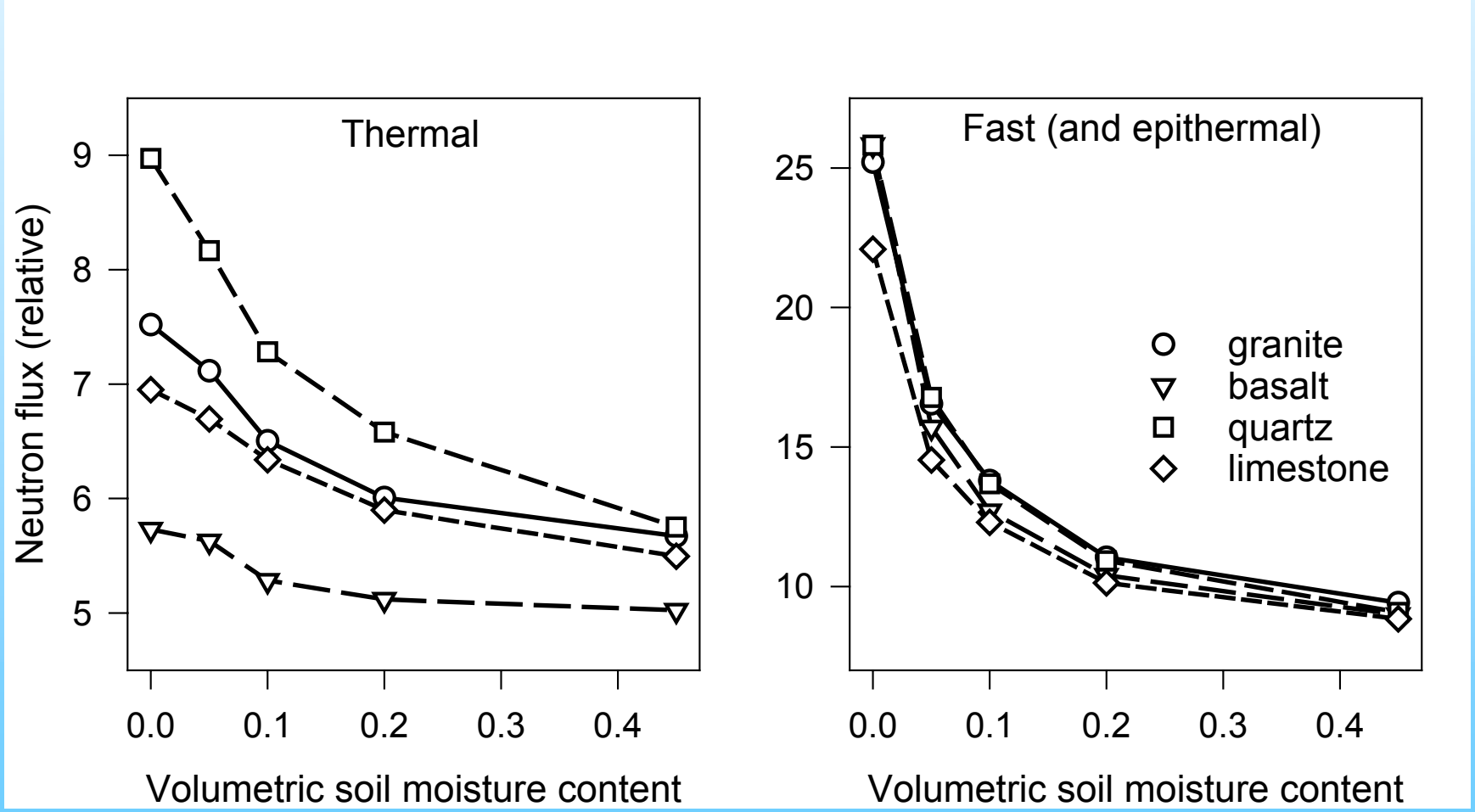
Moderating and absorption properties

Top ten elements (bold letters) contributing to macroscopic scattering and absorption cross sections in an "average rock."

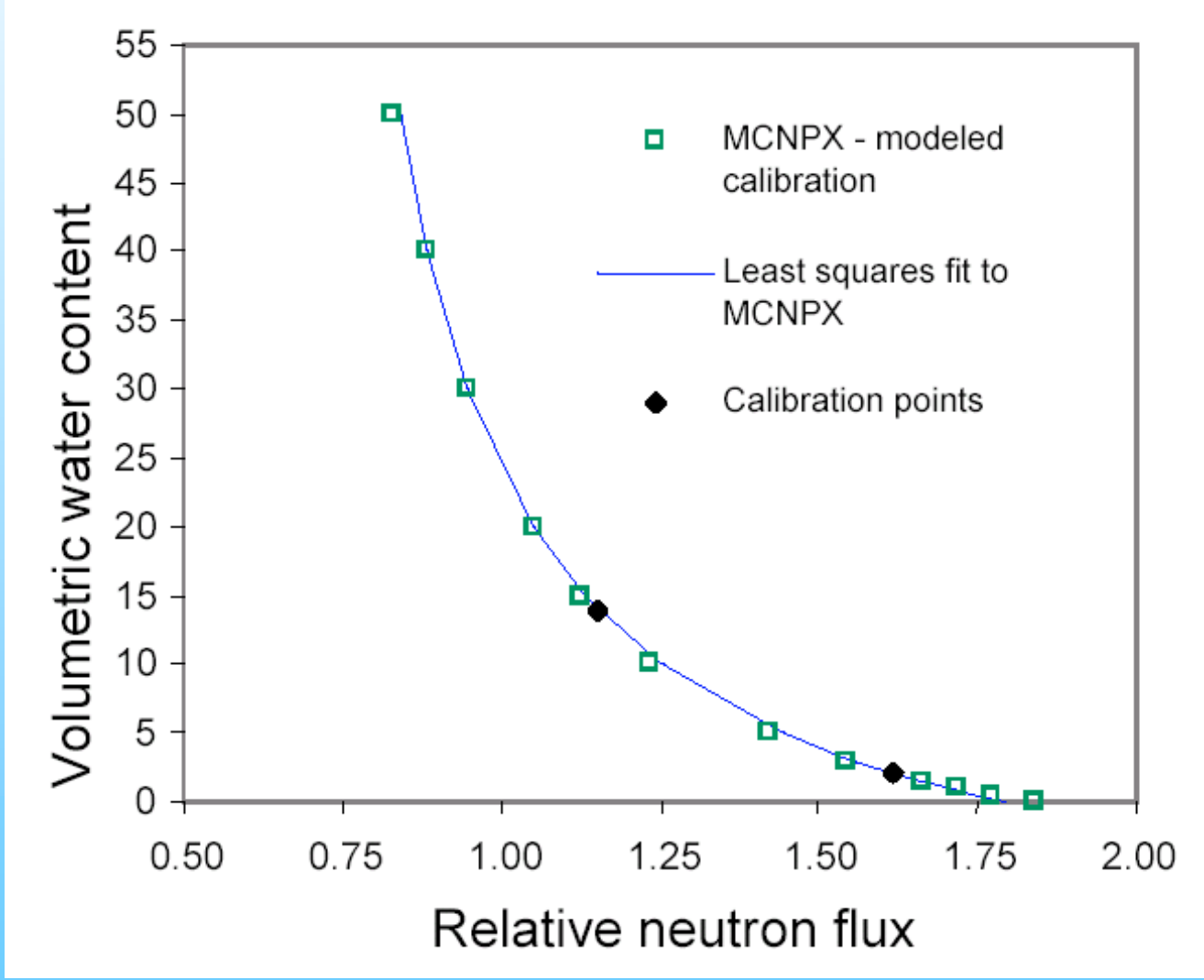
Element	A	σ_{sc}	σ_{th}	NC	ξ	SP
H	1.0079	22.02	**0.3326**	18	1.000	**22.016**
B	10.811	5.24	**767**	103	0.174	0.912
C	12.011	5.551	0.0035	113	0.158	**0.875**
O	15.9994	4.232	0.00019	149	0.120	**0.508**
Na	22.9898	3.28	**0.53**	211	0.085	**0.277**
Mg	24.305	3.71	0.063	223	0.080	**0.297**
Al	26.9815	1.503	**0.231**	247	0.072	**0.109**
Si	28.0855	2.167	**0.171**	257	0.070	**0.151**
Cl	35.4527	16.8	33.5	323	0.055	0.930
K	39.0983	1.96	**2.1**	355	0.050	**0.099**
Ca	40.078	2.83	**0.43**	364	0.049	**0.139**
Ti	47.88	4.06	**6.43**	434	0.041	0.167
Mn	54.9381	2.17	13.3	497	0.036	0.078
Fe	55.847	11.62	**2.56**	505	0.035	**0.411**
Cd	112.411	6.5	2520	1009	0.018	0.115
Sm	150.36	39	5922	1348	0.013	0.516
Gd	157.25	180	**49700**	1409	0.013	2.280

A - atomic mass (g/mole); σ_{sc} - elastic scattering cross-section (barns; 1 barn = 10^{-24} cm^2); σ_{th} - thermal neutron capture (absorption) cross-section; NC - number of collisions to thermalize a 1-2 MeV neutron; ξ - average log decrement of energy per neutron collision; SP - stopping power (roughly equal to $\xi\sigma_{sc}$).

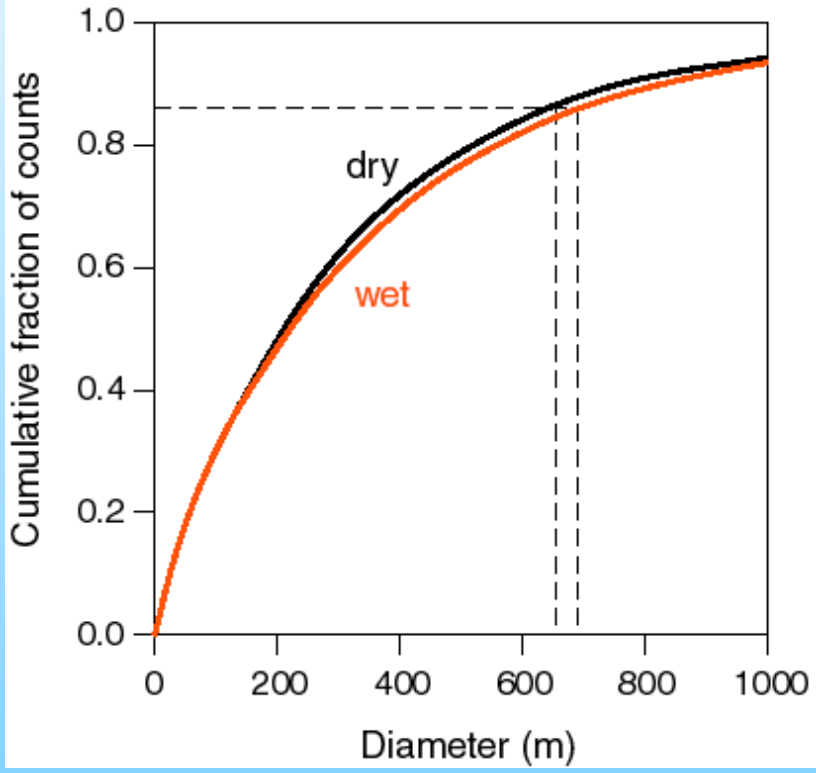
Neutron response to soil moisture

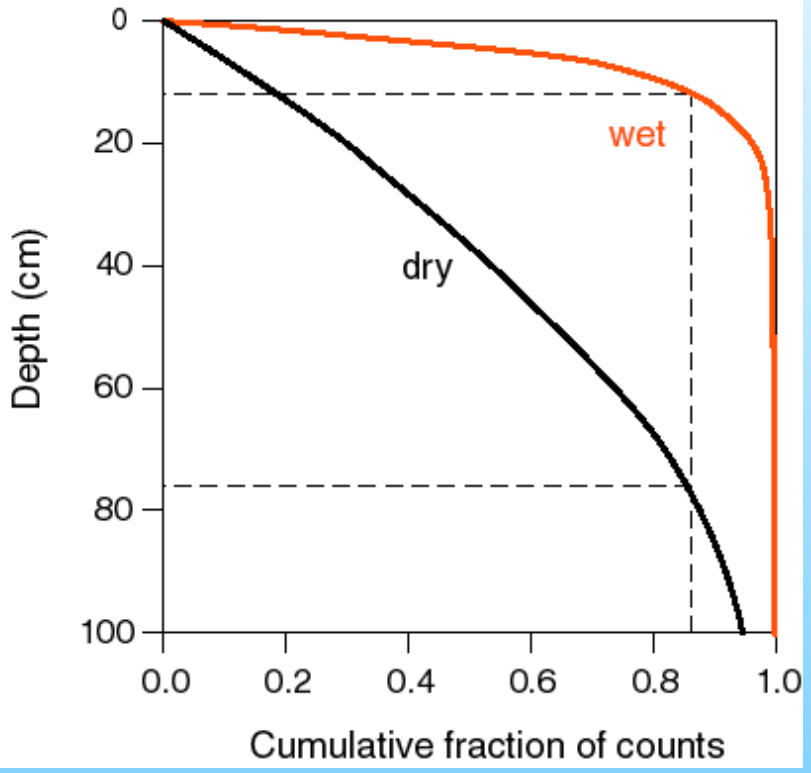


Calibration function



Measurement volume





- 86% of neutrons within radius of 350 m
- Radius increases with decreasing pressure

- 86% of neutrons within depth of 60 cm
- Depth decreases to 12 cm in wet soils

Variations of cosmic-ray intensity

In space:

with latitude and longitude (geomagnetic cutoff rigidity)

with altitude (pressure)

with depth (mass) - not important for this application

In time:

due to pole position changes

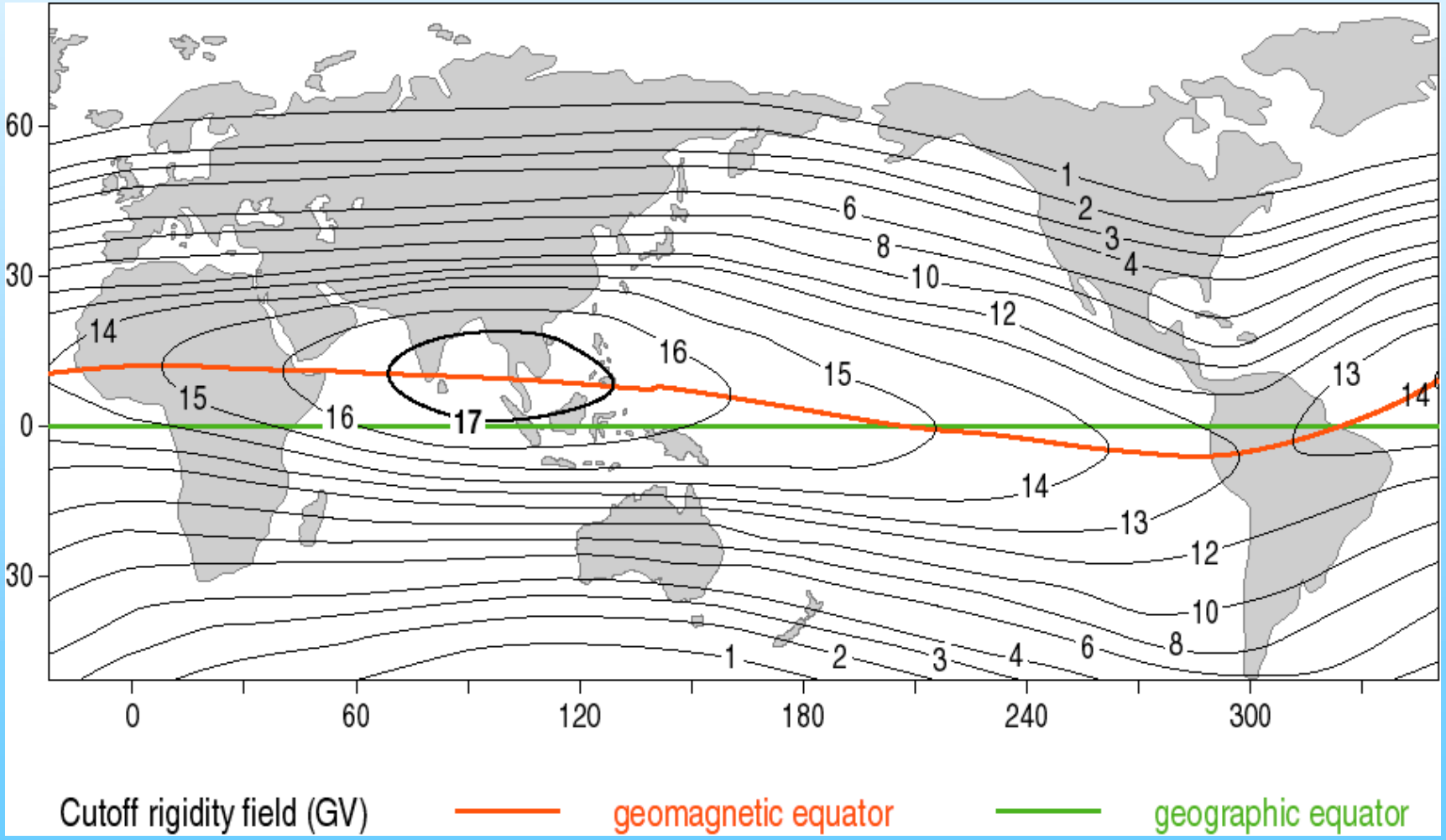
due to solar activity

due to barometric pressure changes

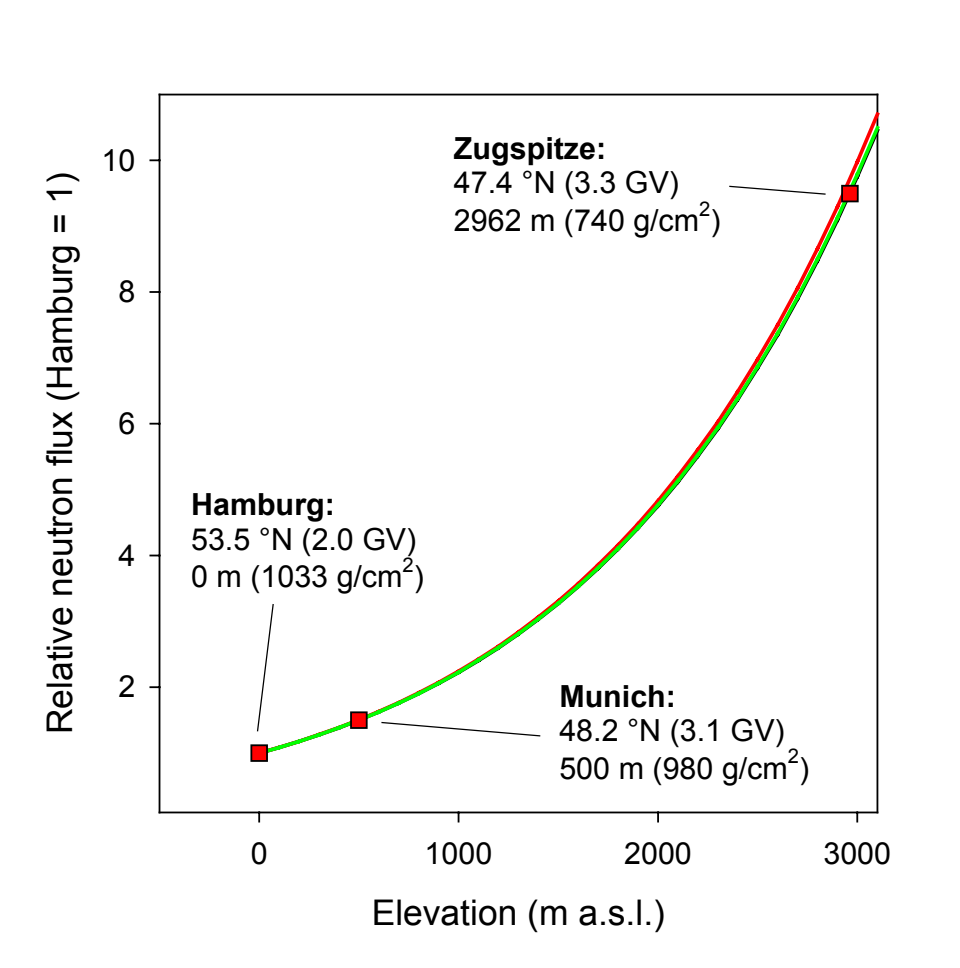
due to paleomagnetic intensity changes - not important

due to long-term galactic cosmic-ray flux changes - not important

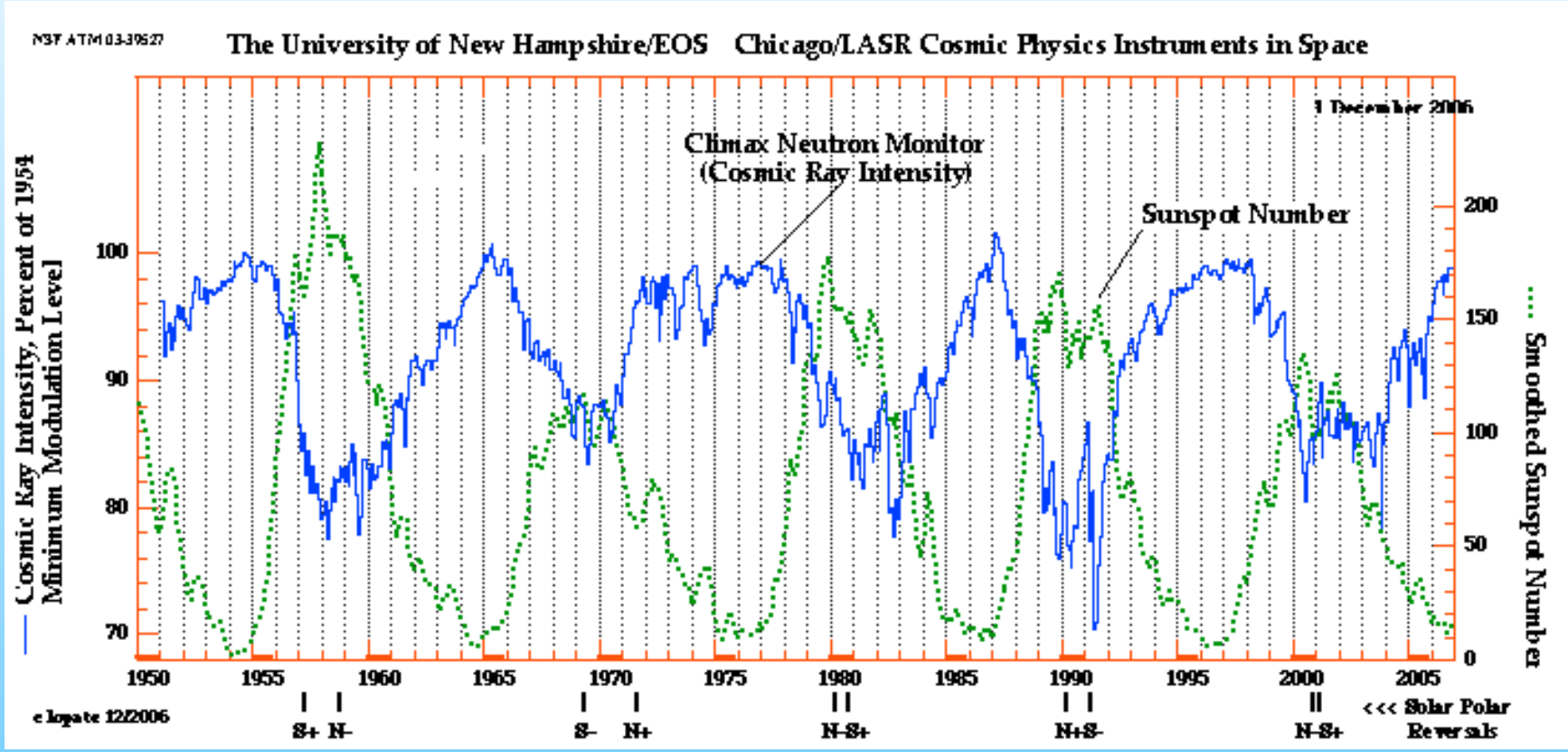
Vertical cutoff rigidity for Epoch 1980



Variations with altitude (pressure)

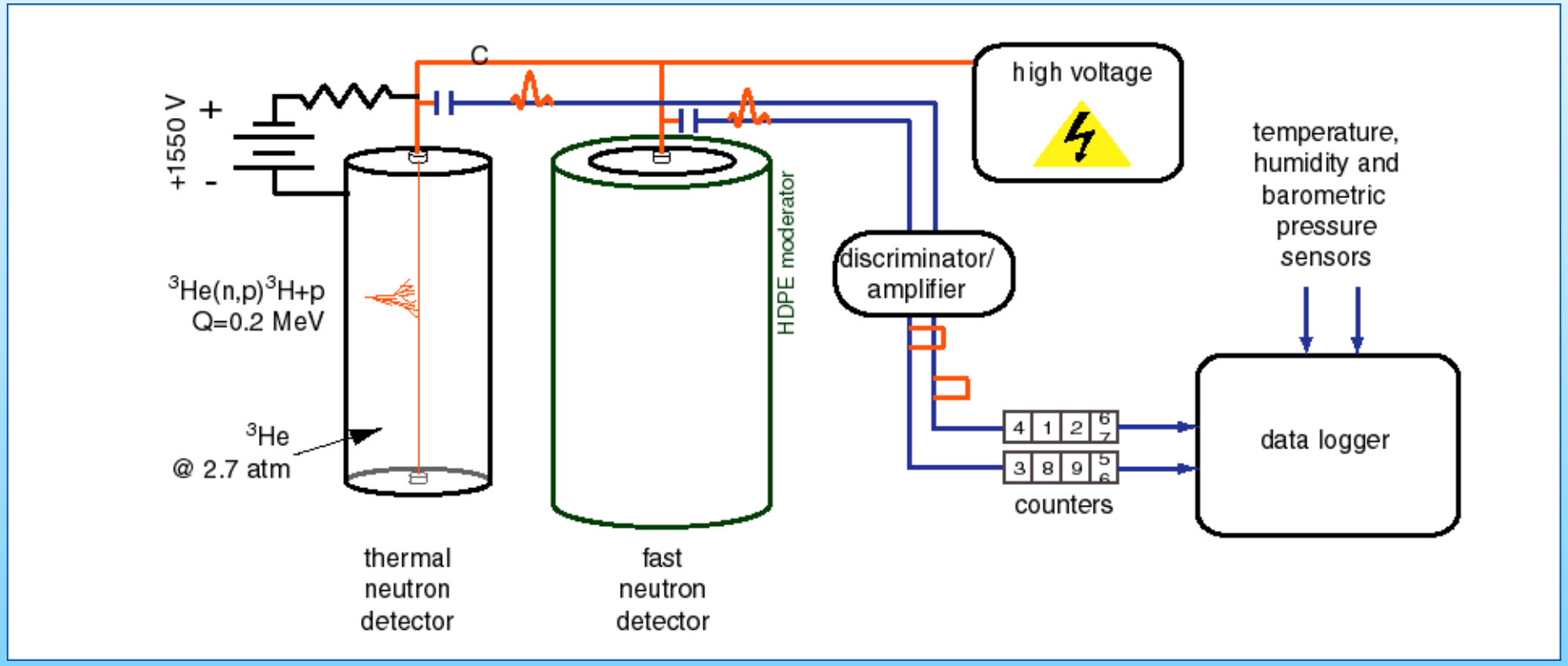


Temporal variations of neutron intensity



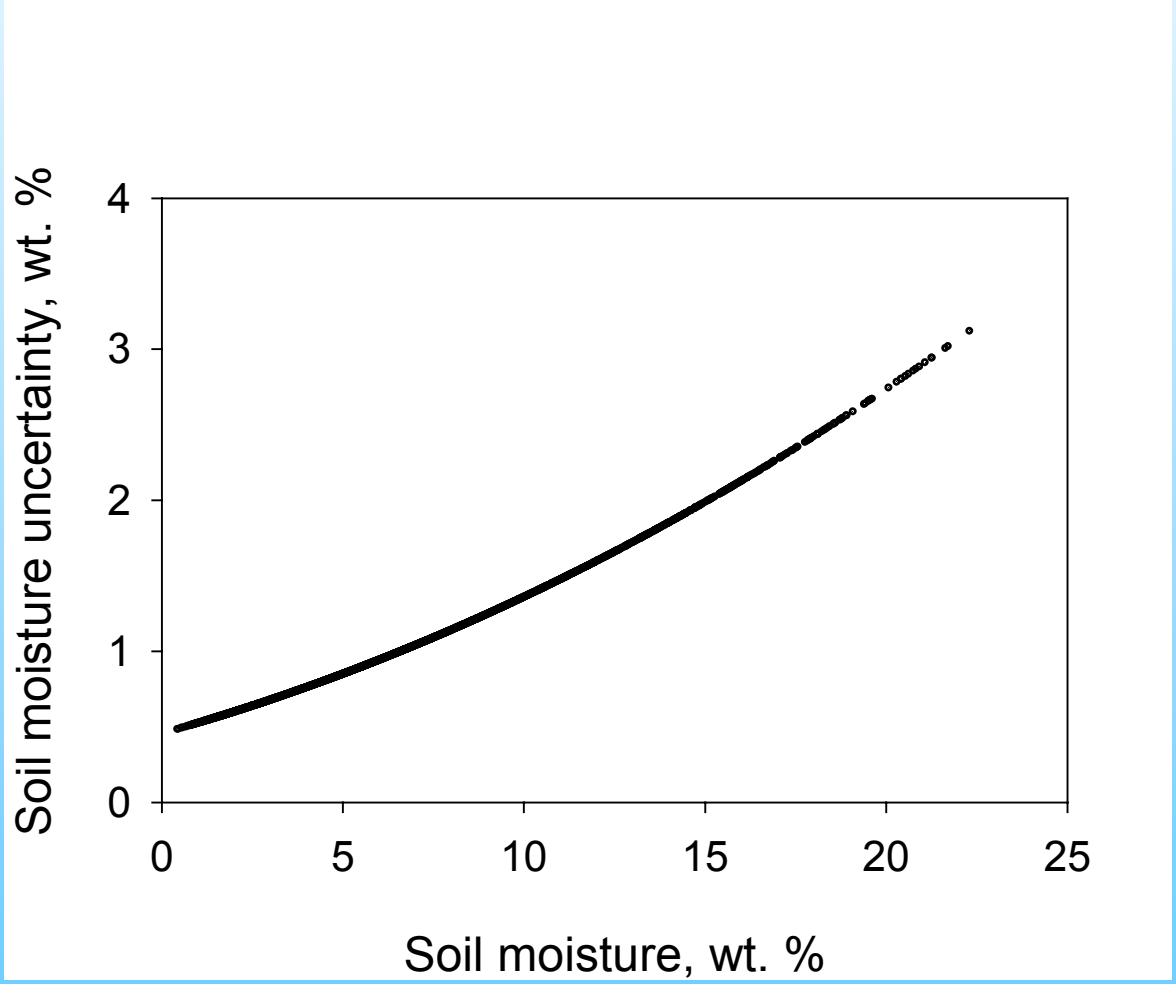
Long-term variations (55 years, five solar cycles): ca. 30%

Cosmic-ray probe



Cosmic-ray probe

Precision of COSMOS probe



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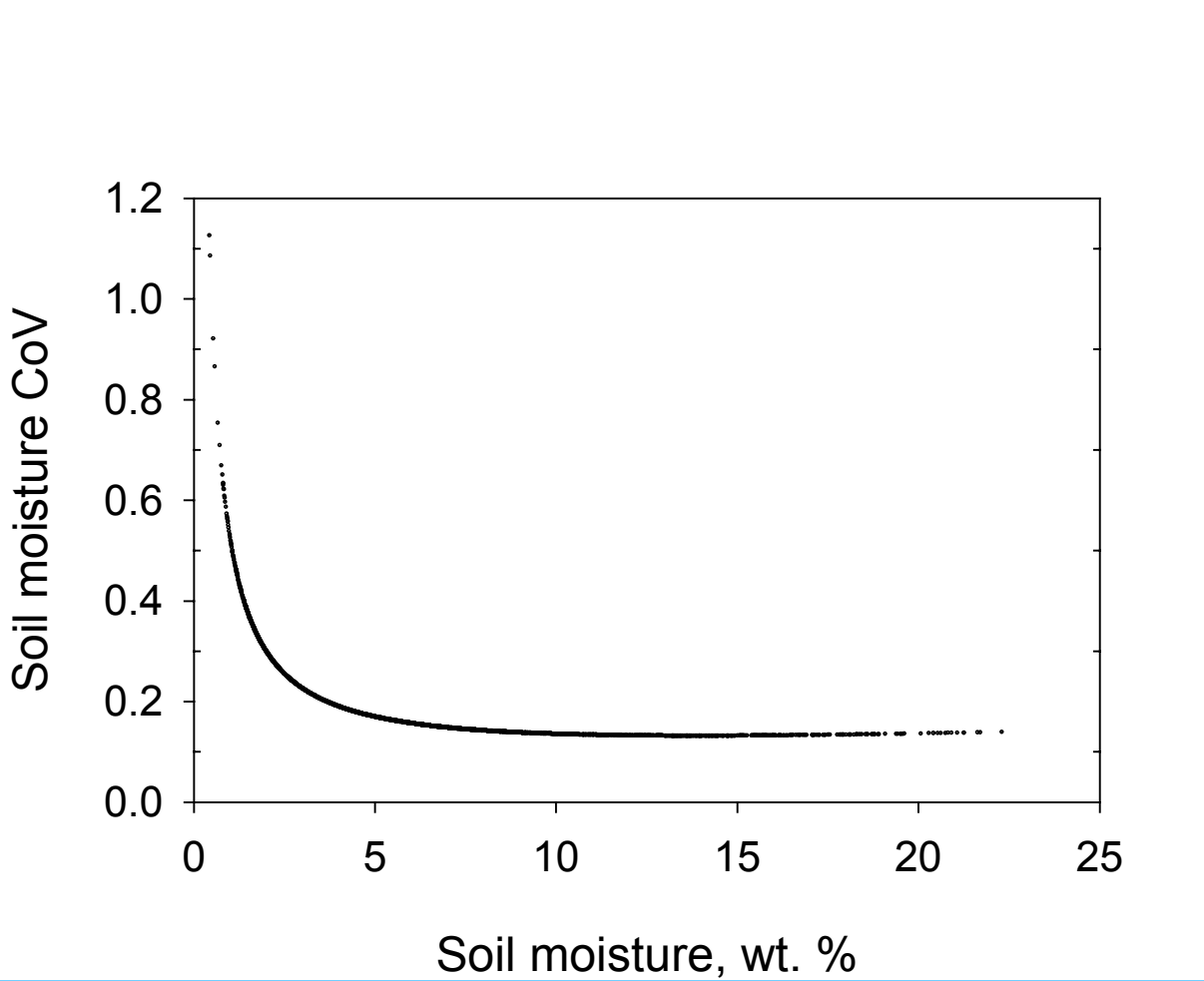
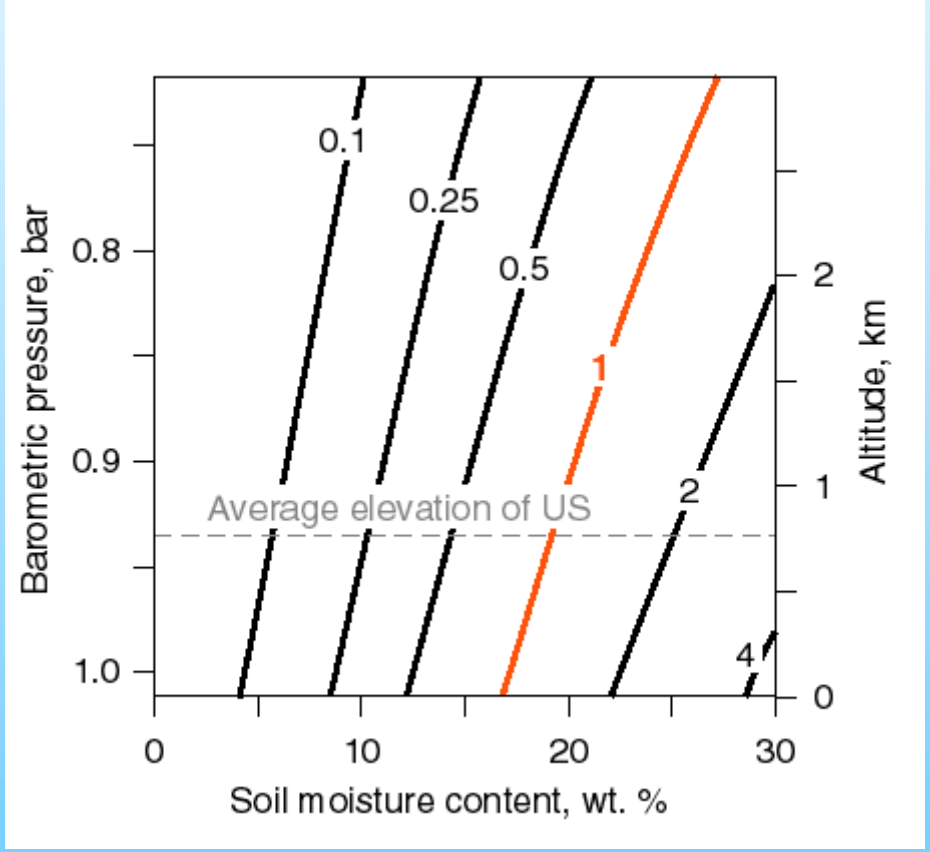


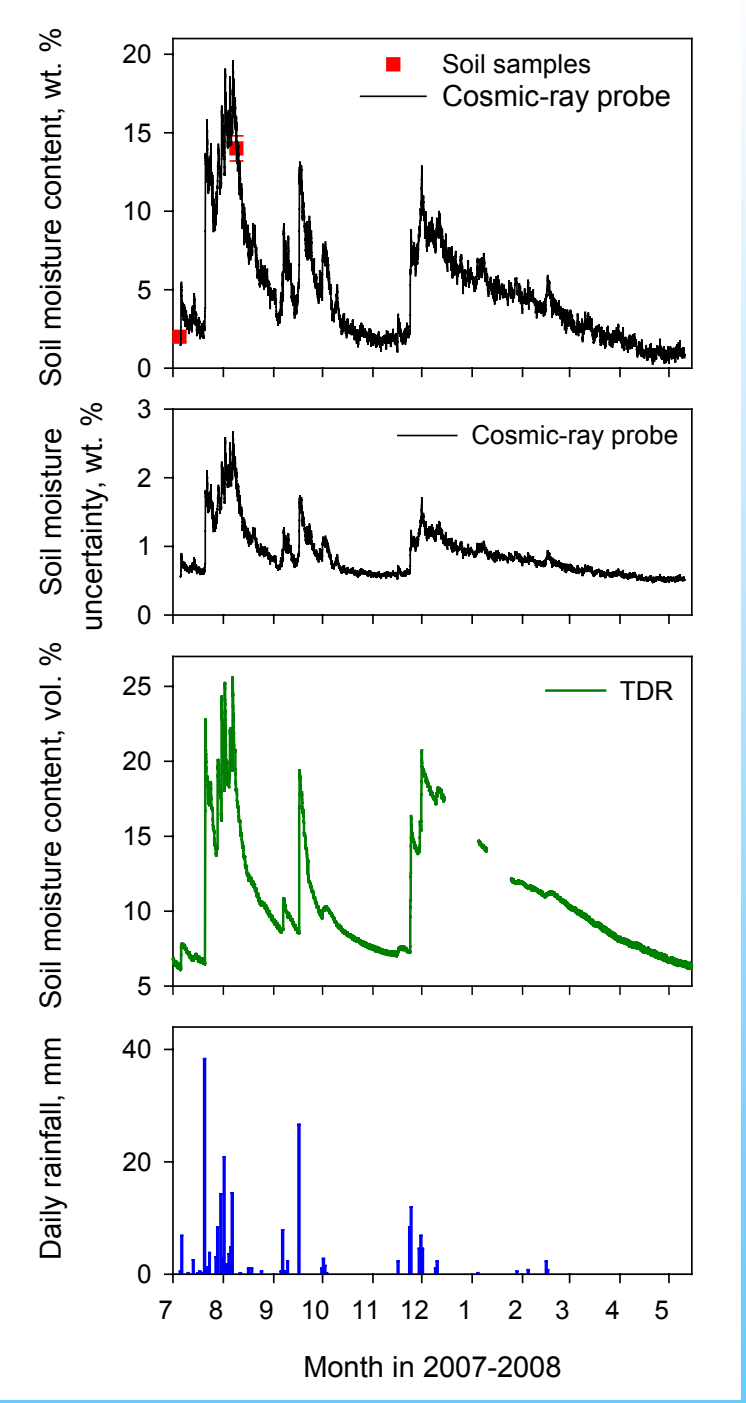
Hours necessary for 2% measurement



Field application
San Pedro River, AZ

- Derived soil moisture from cosmic-ray neutron data
- Compared with gravimetric samples
- With TDR results
- And with precipitation amounts

Cosmic-ray probe, San Pedro River valley, AZ



The cosmic-ray soil moisture probe

Sensitive to soil moisture content

Insensitive to soil chemistry

Non-invasive, no contact measurement

Probe above the ground measures neutrons emitted from soil

No artificial source of radiation

Fully automatic measurement and data transfer

Configurable remotely

Integrated soil moisture over a footprint of ~700 m

Integrated soil moisture over a depth of 12-70 cm

The COSMOS network

(1) 500 stations distributed across the contiguous USA

(2) Each station has a cosmic-ray probe that provides near real-time soil moisture data averaged over a footprint of ~700 m

(3) data can be integrated and reported with arbitrary temporal resolution (the default time is 1 hour)

(3) Each station has temperature, pressure and relative humidity sensors

(4) Intended uses:

(a) soil moisture initialization in weather and short-term climate forecasting;

(b) land-atmosphere energy and mass exchange;

(c) drought monitoring;

(d) ecohydrology;

(e) ground validation of satellite remote sensing methods.